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INTER-PLANETARY MISSION COMMUNICATION SYSTEMS

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Summary

~~It has been stated that~~ The four major functions of communication and tracking systems for inter-planetary missions ~~are~~: tracking, data acquisition and transmission, voice communication, and television have been discussed. Some of the systems which would be required to perform these functions, such as radars, beacons, telemetry, television, voice transmission and receiving systems, antenna systems, and data processing systems, have been presented. It has been shown that some of these systems ~~are~~ being developed are applicable for ~~any~~ any manned space flight mission, while some of the systems development effort is necessary to overcome the ~~particular~~ problems peculiar to ~~of~~ inter-planetary missions. These problems are: (a) signal attenuation at inter-planetary distances, requiring a great amount of power for transmission, (b) the propagation time involved for these signals to span the distances from planet to Earth and vice versa, and (c) the minimal weight, size, and power requirements of these equipments. ~~In conclusion, an attempt has been made to~~ An outline has been given of some of the advanced techniques which are currently being pursued at the Manned Spacecraft Center and of these techniques, optical communication systems, non-voice low data rate communication systems and bandwidth compression, offer the greatest potential of assisting in the solution of manned inter-planetary communication problems.

Introduction

It is anticipated that, in the not too distant future, man will have the capability for inter-planetary travel. In this respect, missions to the planets Mars and Venus are already being considered. It is contemplated that manned inter-planetary missions will have phases similar to the Apollo mission with respect to the orbital phase, deep space trajectories, and rendezvous and docking phases of the missions. This would require that the spacecraft be launched into an Earth orbit and then, at a predetermined time, inject itself into an inter-planetary trajectory. After entering the planet's gravitational field, the spacecraft will orbit the planet first for reconnaissance and then land an Excursion Module on the surface of the planet for an exploratory mission. Upon completion of the surface landing operation and planetary orbital rendezvous maneuver, the spacecraft will launch itself into a return-to-earth trajectory, again orbit the Earth, and finally land back on the Earth. The anticipated time for the Mars mission is [redacted] 420 days; and for the Venus mission [redacted] 400 days.

Since the critical phases of these long duration missions are to be performed at increasingly greater and greater distances from the Earth, it becomes essential that the crew members have a complete capability for command of the spacecraft and operation and maintenance of its systems to assure mission success. It is reasonable to assume that the man-machine system tasks of the crew on these inter-planetary missions will be numerous, with some actions possibly unanticipated and occurring randomly, (that is, treatment of a sick or injured crew member, diagnosis of a faulty system, checking navigation equipment dependability, and so forth). Therefore, it is important that crews have discretionary access to all essential elements of information and every available source of assistance. In this respect, communications and tracking capabilities are of considerable value, not only in providing Earth stations with information on the progress of the mission, but also as an aid to the crew members in performing their operational tasks.

The major functions of communication systems for manned inter-planetary missions are tracking, data acquisition and transmission, voice communications, and television. This paper will present a description of the functions which communications and tracking systems will be required to perform on manned inter-planetary missions, as well as the systems necessary to accomplish these functions. Some of the problems involved, such as transmitter power requirements, gross effects of distance and signal propagation time, frequency selection, and weight and size of equipment will be discussed; and an attempt will be made to indicate the general nature of communication equipments to be employed. Many of the technical problems which confront the communications-systems designer are brought about by the geometry of the mission profile with regard to orbital excursions, deep space trajectories, and attitudes of the spacecraft. Several advanced techniques presently under investigation, which may aid in the solution of these problems, also will be presented.

Communications Major Functions

In order to simplify vehicle electronic systems, a unified communication frequency is expected to be used for all four communication functions. This concept is portrayed in Figure 1 as the Unified Carrier link.

Tracking Functions.

During the entire mission, it is desirable that tracking links exist between the spacecraft and Earth-based stations, between the Mission Module and Excursion Module and the planet (for reconnaissance and landing operation), and between the Earth-entry Module and recovery forces (for recovery operations). Earth-based stations must track the spacecraft from initial launch, throughout inter-planetary operations and the return to Earth. This requirement necessitates that position and velocity vectors be known at all times for inter-planetary flight, and it would be highly desirable to obtain the same information from the Excursion Module during its planetary operations. The Unified Carrier link will support both near Earth and deep-space tracking functions whenever there is a line-of-sight path available between the spacecraft and Earth.

After the spacecraft has reached the vicinity of the planet, it will execute an orbit in performing a reconnaissance prior to landing. During this phase of operation, an integrated landing/rendezvous radar is needed for orbital navigation, landing, lift-off, space rendezvous and docking. For the landing mission, the radar system must measure height above the surface, vertical velocity, horizontal components of velocity, and drift angle if a windswept atmosphere is encountered. Technical complications arising from rocket exhaust and planetary dust must be considered in selecting the radar frequencies. The integrated radar system must combine the characteristics of acquisition and tracking to furnish relative range, closing velocity, and angular information of the Excursion Module with respect to the spacecraft so that the spacecraft can be inserted into the proper ellipse for the rendezvous maneuver.

The primary tracking function is to be provided by the Unified Carrier link. By utilizing pseudo-random code techniques, it is possible to provide range at inter-planetary distances with a theoretical accuracy of ± 15 meters and a resolution of better than 15 meters. Two-way radial doppler operation for real time velocity determination can be obtained at all ranges as long as the signal-to-noise ratio is sufficient to maintain carrier lock. The distance to which this can be maintained is dependent upon the antenna gain, receiver sensitivity, and power output of the spacecraft transponder system.

Spacecraft equipment required to perform this function includes: coherent transponders, power amplifiers, antennas and a range unit on board the Orbiting Spacecraft and Excursion Module. The range unit is a code regenerating device which eliminates the noise from the received code before retransmission at long ranges. This device would be used on deep space trajectories; however, at shorter ranges, the range unit would not be needed since the received signal-to-noise ratio would be high and a turnaround system could be used. The turnaround technique is much more flexible, as the spacecraft systems are merely required to retransmit the received code. While in this mode, the Earth-based stations can vary the ranging technique to optimize the acquisition time and accuracy in the near Earth phases without modification of the spacecraft systems. Since the tracking function will add very little to the antenna gain and the power amplifier requirements, other onboard functions will dictate the magnitude of these parameters.

When the rendezvous radar system is used, a single beam will be transmitted probably by using coherent pulse techniques or interrupted

CW transmission with a 50-percent duty cycle. In order to conserve power, the rendezvous will be a cooperative operation, utilizing transponders on the Orbiting Spacecraft. Angle measurements can be made using interferometer techniques to insure accuracy at short ranges. At long ranges, a high-gain antenna using scanning techniques could be employed. It is considered that this radar technique can be implemented by adding another mode to the altimeter radar or by using the coherent capabilities of the Unified Carrier transponder.

It is expected that the altimeter radar will operate at X-band to take advantage of proven component experience and the high-gain antenna capability at these frequencies. High altitude measurements can be made by using a single beam pulse radar techniques. Lower altitude measurements can be made by using up to three beams with FM/CW or ICW techniques. The three beams will allow horizontal and vertical velocities to be measured. It is anticipated that the angular patterns of these beams will aid somewhat in minimizing the effects of exhaust plumes and planetary dust. The major problem appears to be in the efficient generation of sufficient power at X-band frequencies for long-range use.

The tracking function during recovery of the spacecraft after it has landed back on Earth needs no extensive elaboration in this paper since this function will not be peculiar to these missions. Recovery tracking systems would include both HF and VHF beacons compatible with existing recovery support facilities. All manned space missions whether near Earth or deep space will utilize basically the same recovery tracking equipment compatible with direction finding aids available in aircraft, aboard ships, and at ground stations at the time of the missions. These aids will provide the capability of automatic direction finding from recovery aircraft and fixed stations using long range direction finding equipment for approximate location of the broad search and recovery area and line-of-sight techniques from about 100 nautical miles for precise position fixing of the reentry vehicle.

Data Acquisition and Transmission Function.

The communication links necessary to perform the data transmission function are shown in Figure 2. Some of the typical kinds of data to be handled by the data links are: crew conditions, spacecraft environmental conditions, systems conditions, scientific data, and navigation and guidance information. Data may also be sent to the spacecraft from ground stations over the voice link as well as over the up-data link.

With regard to the data link, as well as the other functions, the geometry of the mission presents some interesting problems for consideration. One of these is the fact that regardless of the type of planetary orbit, direct line-of-sight communication with Earth will be possible only a little over 50 percent of the orbital time. For this reason, when the spacecraft is orbiting the planet, the time in which data may be transmitted to and received from the Earth is limited and must be used efficiently to transmit and receive the maximum amount of information possible. Another geometric problem is the effect of the planetary orbit on the Orbiting Spacecraft-to-Excursion Module links. Depending on the altitude of the orbit, this link will be active only 10 to 20 percent of the orbital time, since at other times the orbiting module will be below the planet's horizon and therefore not in line-of-sight of the Excursion Module.

The Sun, the Moon, other planets and their moons can also cause interference with communication links for short periods during some planetary missions. The major problem in this area is the Sun since it is a high-level noise generator which can degrade the communication at any time it is near the field of view of the antennas.

Because of the time element involved in free space signal propagation and the "masking" effect when the spacecraft is behind a planet and not in a position to transmit to Earth, data must be stored on board until such time as it can be communicated. A tape recorder-reproducer system is proposed for this purpose. Another important system factor to be considered is one to which reference was made earlier and that is, if the crew is to have a complete command capability, onboard processing and extraction of essential elements of data must be accomplished as an aid in their decision making.

The systems required to implement these functions must emphasize minimum error techniques in preference to high data rates. Low data rate PCM systems are being recommended in the deep space phases with the capability for higher rates in the near Earth phases and intermittently throughout the remainder of the mission using the high-power transmitting mode. These data are expected to be bi-phase modulated on a high frequency subcarrier which, in turn, will be phase modulated on the main Unified Carrier for deep space communications.

It has been calculated that it is possible to transmit 100,000 bits per second from Mars and Venus with a transmitter power of about 100 watts by using a 10-foot spacecraft antenna and a 210-foot Earth antenna equipped with the best receiving equipment. A low data rate mode including voice and minimum data functions, could probably perform satisfactorily with about 10 watts of RF power.

Physiological and suit environmental data will be introduced into the main data stream through umbilical cables attached to the crew members' suits while the crew is inside the spacecraft. When the crew is outside the Excursion Module, the crew data is expected to be transmitted along with voice to the Excursion Module over a VHF link for possible relay to the Orbiting Module, by multiplexing on the VHF voice link, or to Earth over the Unified Carrier link.

Data from Earth to spacecraft will be transmitted over the Unified Carrier link by using PCM techniques similar to those employed on the Gemini Program. These data will be multiplexed with the voice and range code signals by using subcarrier techniques. Terminal equipment for decoding, displaying, and using these data may be provided in both the Orbiting Spacecraft and Excursion Module.

Voice Communication Functions.

Voice communication is an obvious function, but one which becomes increasingly important with increasing crew sizes. The links required for this function are shown in Figure 3. It is noted from this sketch that two-way voice communication is available between all modules, crew members, and Earth whenever a line-of-sight path exists.

At this point, it is well to mention that there exists a problem of signal propagation elapsed time, due to the great distances involved between terminals of the spacecraft-to-Earth links at planetary distances.

This problem exists for all communications and tracking links, but the disconcerting effect of the time lag would be most noticeable in the voice communication function. It has been calculated that over the distances at which Mars or Venus, our closest planets, are in opposition to Earth, signal propagation time from Earth to either Mars or Venus will take a minimum of 10 minutes (up and down). This relatively long period required to transmit and receive messages will definitely reduce the effectiveness of speech as a spacecraft-to-Earth communication technique except in the near Earth phases.

For communication with Earth from the spacecraft at deep space distances, voice is expected to be modulated on a subcarrier which, in turn, will be phase modulated on the main Unified Carrier link. The capability will also exist to phase modulate the carrier directly while the transmitter is operating in low-power modes. Because of the time involved in a two-way exchange of information at great distances, voice communication possibly may be eliminated at these distances in favor of a system similar to teletype.

VHF links will be used for voice communication between the Orbiting Spacecraft and Excursion Module. This link will require about 50 watts of power unless directional antennas are used.

If the astronaut finds it necessary to leave the protective environment of the spacecraft during the flight phase or to investigate the surface of a planet, he must have the capability of communicating with the Excursion Module, Command Module, and other crew members. The systems required to perform this function are similar to those being developed for the Apollo mission. The personal communication system should have the capability of acquiring and transmitting several channels of telemetry data along with duplex voice.

During the recovery operation, voice communication with long range location stations as well as communications with recovery craft will be necessary in order to coordinate the recovery operation, report the condition of crew systems, and obtain necessary medical or survival information.

Television Functions.

Television aboard a manned planetary spacecraft can perform several functions including viewing of the docking operation, hazard monitoring, data transfer, and public information.

The communication links required for transmission of television are shown in Figure 4. Again, the Unified Carrier link serves to transmit the TV pictures from the Orbiting Spacecraft and the Excursion Module to Earth. A link will be required between the individual modules and between the Excursion Module and crew members working on the planet's surface.

Technical investigations currently are being conducted with a view toward obtaining a television system for use on the Apollo mission. As a result, it will be possible to generate parameters which, hopefully, can lead to the development of lightweight deep space television systems for use on planetary missions.

The use of television during manned inter-planetary missions depends on the weight, volume, and power which can be allotted to this function. The transmitter power is directly related to the information bandwidth of the video signal. Commercial type TV exhibits a wide bandwidth such that prohibitive transmitter power would be required to send the signal with satisfactory fidelity from deep space. Therefore, television transmitted from deep space is not feasible unless the video signal information bandwidth is reduced considerably. This problem is already being faced in the Apollo Project, wherein the bandwidth is being reduced from the 4.0 mc of commercial type TV to 360 kc by the use of a frame rate of 10 frames per second and a line number of 278. This scheme provides a generally satisfactory picture although picture quality is marginal in some respects. Even this television system with reduced bandwidth would require approximately 1,000 watts of transmitter power using the Unified Carrier system on a Mars or Venus mission. For the deep space missions, taking into account the limited power available, more sophisticated TV bandwidth compression techniques will be required than those currently being considered for the Apollo Project. There are a number of possible techniques for processing this signal to effect further bandwidth reduction. Present investigations are primarily concerned with means of efficiently encoding the signal and eliminating much of the redundancy inherent in a conventional video signal.

Overall Systems Considerations.

For deep space telemetry, television, tracking, and voice communications, a directional antenna should be provided, mounted on the Mission Module in such a manner that it can be properly oriented toward the Earth at all times. An Earth sensing system should be incorporated into the antenna system to maintain a constant relationship between the Earth and the antenna even though the spacecraft may be rotating to simulate gravitational forces. An antenna approximately 10 feet in diameter having a gain of approximately 35 db has been considered. Antenna size will be limited by problems of storage and integration with other spacecraft systems. Antenna gain should be, of course, as high as possible in order to reduce transmitter power requirements. Gain, however, is limited by antenna size and problems of pointing narrow beam antennas.

Also, the antenna should be of the erectable type to allow stowage within the vehicle during launch and high "g" phases such as injection into Earth orbit and into inter-planetary trajectories. This need for stowage arises from the fact that an externally mounted structure of the size and configuration necessary for the deep space antenna cannot withstand the tremendous forces generated during launch and high "g" phases of the mission. When the critical phases of the mission are completed, the antenna will be deployed to its operating configuration.

Now that the major functions of tracking, data acquisition and transmission, voice communications, and television have been discussed and the individual systems to perform these functions have been outlined, let us see how these systems could be integrated into an overall system complex. Figure 5 shows the systems as they would be used aboard the Excursion Module. These include: a VHF transceiver, an antenna selector, a Unified Carrier transponder and power amplifier, a telemetry PCM encoder, a decoder, an intercommunication system, a range unit, a storage unit, a television system, a relay transceiver, personal communication transceivers, rendezvous and altimeter radars, a rendezvous transponder, and both high gain and omnidirectional antennas.

The block diagram of the systems used aboard the Mission Module is shown in Figure 6. These include all the systems mentioned for the

Excursion Module plus a VHF recovery beacon, an HF recovery beacon, an HF transceiver and multiplexers. This additional equipment is necessary for the recovery operations following Earth landing.

With some redesign, several of the Apollo systems may be suitable for use on inter-planetary missions but, in most areas, new development must be performed in order to capitalize on new techniques and advancing state-of-the-art in communications and instrumentation. Systems such as the VHF and HF recovery beacons, the VHF voice transmitters and receivers, intercommunication and personal communication systems will be similar to those used on any of the manned space missions. The major areas for system development effort will be: the Unified Carrier transponder with regard to power and bandwidth requirements; the telemetry system, data processing and storage systems with regard to data rates, bandwidth, onboard processing, transmission techniques and power requirements; the television systems with regard to power/bandwidth reduction and transmission techniques; and the antenna system with regard to size, gain, efficiency, location, and vehicle integration.

Advanced Techniques.

So far, the discussions presented in this paper have been concerned principally with systems presently under consideration for planned interplanetary missions. At this time, let us examine some investigations and studies of advanced techniques being performed at the Manned Spacecraft Center, which might possibly replace or improve certain aspects of these presently proposed systems.

Optical Communication Systems. Because of the immense distances involved in signal transmission from the planets, a narrow and concentrated beam is desirable for efficient energy transfer in the space communication circuit. This type of communication system could be obtained by using a LASER. Studies are presently being sponsored by the Manned Spacecraft Center to evaluate LASER systems in comparison with present RF systems. During the comparison of the two systems, a preliminary optimization was made of the possible optical transmission paths. The path schemes considered are:

1. Direct optical link between Earth and a deep space vehicle.

2. Microwave link from Earth to an Earth orbiting satellite followed by a repeater optical link from the satellite to the deep space vehicle.

3. Microwave link from Earth to Moon with repeater optical link from the Moon to the deep space vehicle.

Acquisition and tracking of the spacecraft's position to extremely high accuracies is required where narrow beam techniques are used. The stringent stability requirements for pointing and tracking the spacecraft radiating system also impose serious problems when narrow beam techniques are employed. These problems are under study and their solutions must be attained before suitable equipment can materialize from development.

Still other problems confront the optical techniques. Among these are the basic laws governing refraction and attenuation of the optical beam due to the Earth's atmosphere and cloud cover. These problems will also apply to some of the planets containing atmospheres. Solution of these problems would include relay over microwave links from moons of the

Earth and the planets, on an intermittent basis or from a chain of communication satellites about the Earth and/or the planets.

Optical antenna gain limitations due to atmospheric diffraction fluctuations tend to indicate a need for use of a satellite relay station as part of the implementation of the optical transmission approach. Dispersion effects will broaden an Earth-based optical system beamwidth while fluctuations in atmospheric diffraction can cause fluctuating pointing errors as great as 25 microradians at zenith. The requirements on servo systems needed to nullify the effects of this motion on large astronomical mirrors are severe; hence, a practical 25 microradian beam limit for an Earth-based optical station can be inferred. Of course, these effects are of negligible proportions in the case of the lunar environment.

The results of a system reliability and geometrical coverage analysis for the considered inter-planetary optical path indicate that at least one and probably two communication satellites, synchronous with the objective planet, will be needed to provide continuous contact with the deep space vehicle. In order to provide the capability for a continuous optical link to Earth without satellite relays, desert locations should be chosen for ground stations in preference to mountainous regions because of the lower incidence of interfering cloud cover.

Another potential use for an optical system is that of optical radar. In an optical radar altimeter system, many of the advantages common to a narrow-beam high-frequency radar system could be available with possible savings in equipment size and weight. This type of radar may be capable of penetrating the spacecraft exhaust plume and reentry plasmas and could also be gainfully employed as a rendezvous and docking system by using wider beam techniques.

Low Data Rate Communication System. In communication systems, accuracy can usually be improved by reduction in data transmission rate. One of the presently known techniques to accomplish this is the decreasing of bandwidth to improve signal-to-noise ratio. Another technique for improving the accuracy of signal transmission is by the use of feedback, although there is a major disadvantage, i.e., signal transmission time at inter-planetary distances would become excessively long. A third method of improvement is one in which error correcting codes are used, but this method would require an increase in the complexity of the communication system and also result in less information being transmitted. Some of the techniques being considered are standard teletype transmission systems, code wheel techniques, x-y recorder techniques, facsimile techniques, and standard Morse code techniques.

In evaluating the feasibility of the various techniques, it becomes apparent that two major problem areas are immediately presented; namely, the input unit and the output unit. By input and output units we refer to the method used to introduce the information into the transmitter and the method of displaying the responses from the ground stations to the spacecraft crew. Presently, the teletype technique appears most promising.

In choosing any particular non-voice transmission technique, consideration must be given to what information would be best handled by this system. If the information is of a predictable nature, it can be programed for transmission with the telemetry data. Under this condition, a non-voice system serves no real purpose since a low rate PCM telemetry system would be superior. But, if the information is of an unpredictable nature, such as a unique discovery in space, an emergency regarding a crew member or a peculiar spacecraft condition, a non-voice low data rate communication system relying on crew intelligence would best serve to transmit these data with the greatest accuracy and within a narrow bandwidth.

Bandwidth Compression Techniques. In order to increase the capability of transmission of television, voice and other analog data, these data must be compressed as much as possible while maintaining the original information content. Many studies are in progress which analyze these signals to determine the best processing techniques required to perform this function. These processes include vocoders, comb filters, and redundancy sensing and elimination techniques for bandwidth reduction. There are two main reasons for investigating bandwidth compression techniques: the first is to conserve bandwidth when using a number of subcarriers in a frequency multiplexing system; the second is to decrease the noise power, which is a direct function of bandwidth, and thereby increase the signal-to-noise ratio while decreasing the transmitter power output and, therefore, weight and volume of the equipment package as well as the primary power input. The problem of bandwidth compression is not purely one of maintaining information content while decreasing bandwidth, since there are physiological factors which enter into consideration, such as the eye's capability of integrating a repetitive signal, for example, in the case of television. Therefore, a certain amount of subjective analysis is required when analyzing bandwidth compression techniques. The major part of our present effort is directed toward television bandwidth compression.

Because of the large bandwidth involved as well as the large amount of redundancy which conventional video signals exhibit, this appears to be a fruitful area for a significant reduction of bandwidth and power requirements. In the area of speech bandwidth compression, a number of techniques are under investigation; and these studies will be pointed toward obtaining a signal which is quite substantial in the presence of noise. Along these lines, a method of sampling the speech spectrum with narrow bandpass filters is presently under study. Most of the known techniques of speech bandwidth compression appear to require equipments which are too massive for use onboard spacecraft and exceed reasonable payload limits. The use of thin film solid state devices and microminiature integrated circuits will be studied further to determine their feasibility and application to solution of these problems.

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Figure 1

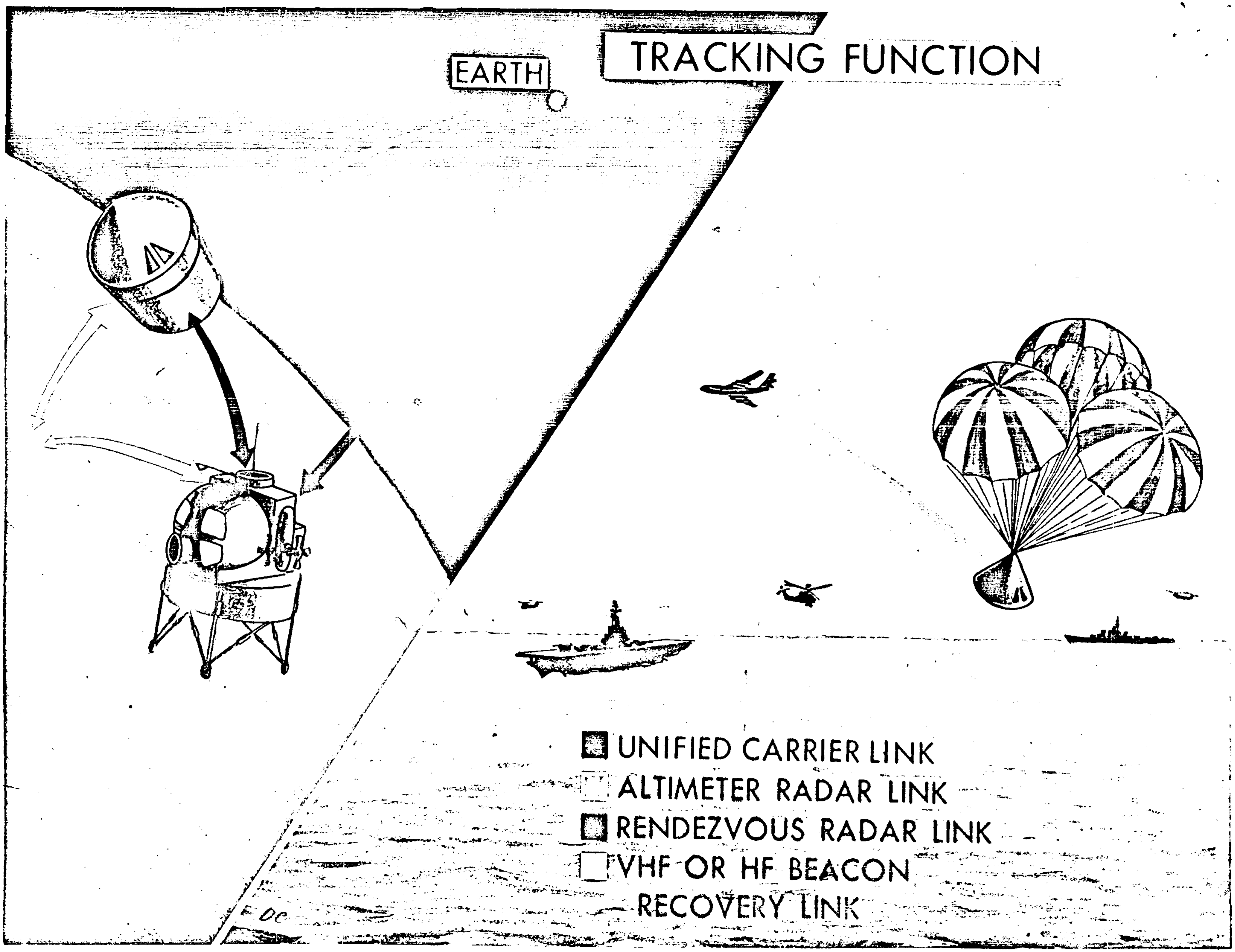
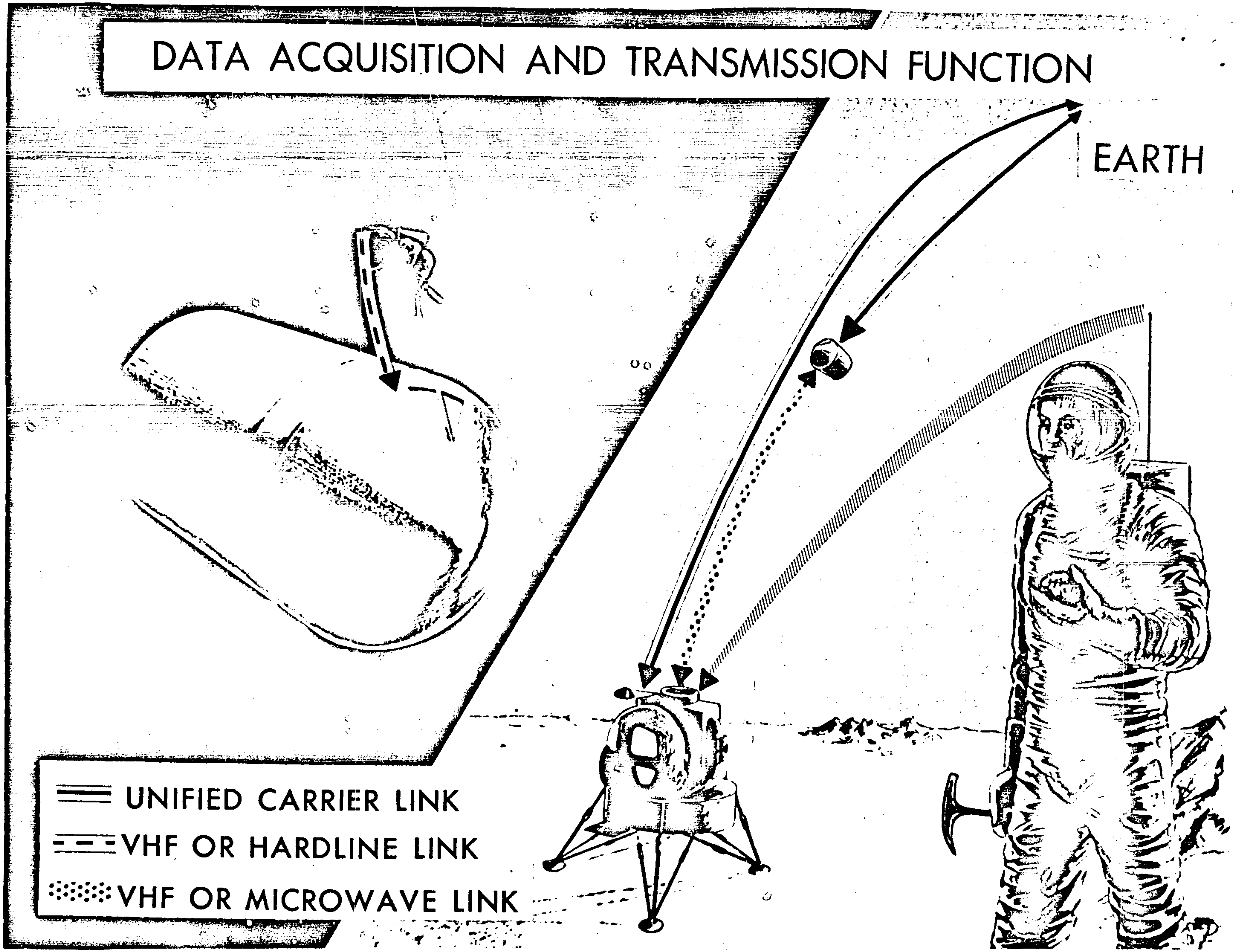
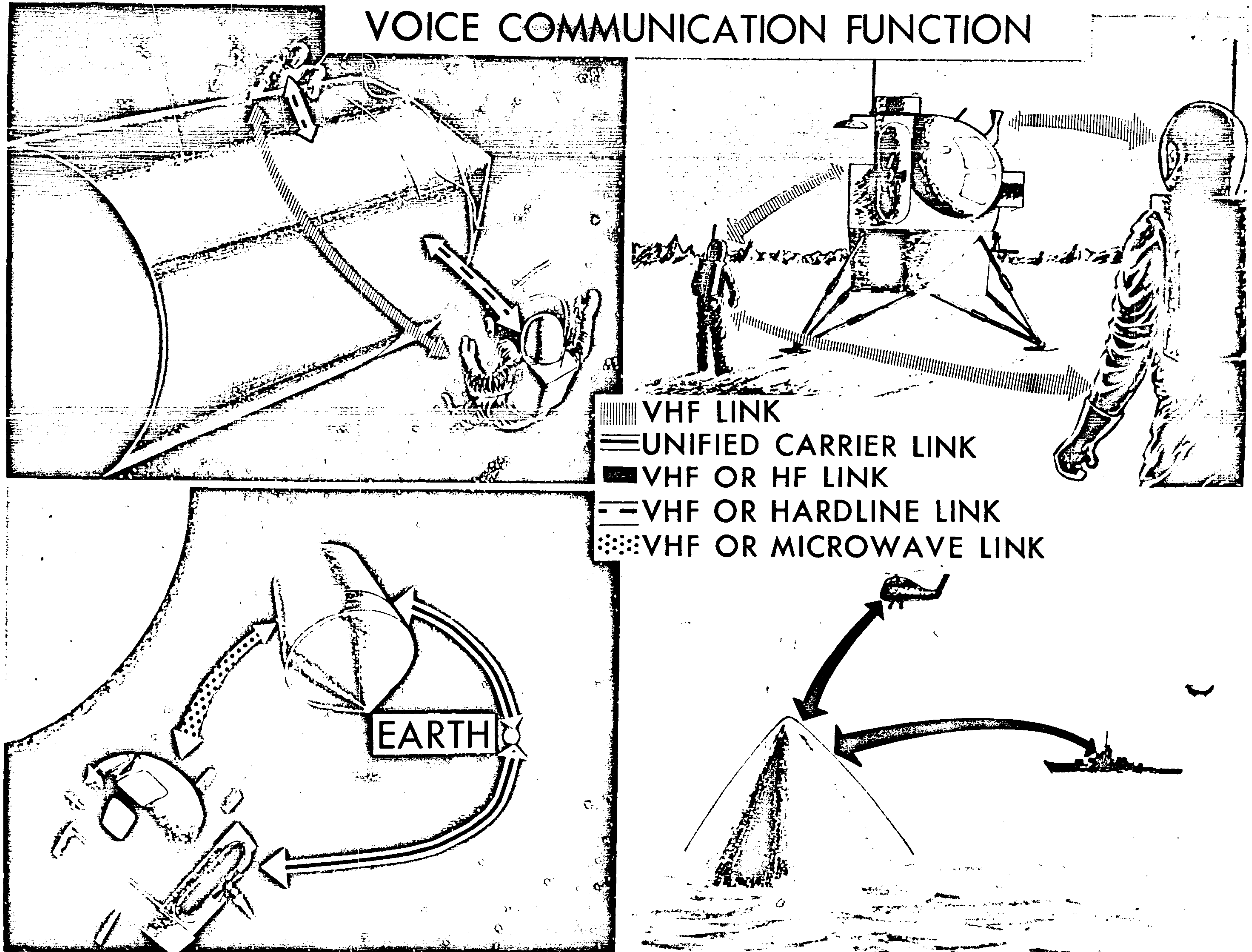


Figure 2


DATA ACQUISITION AND TRANSMISSION FUNCTION
EARTH
UNIFIED CARRIER LINK
VHF OR HARDLINE LINK
VHF OR MICROWAVE LINK

S-63-12025

Figure 3



S-63-10043

Figure 4

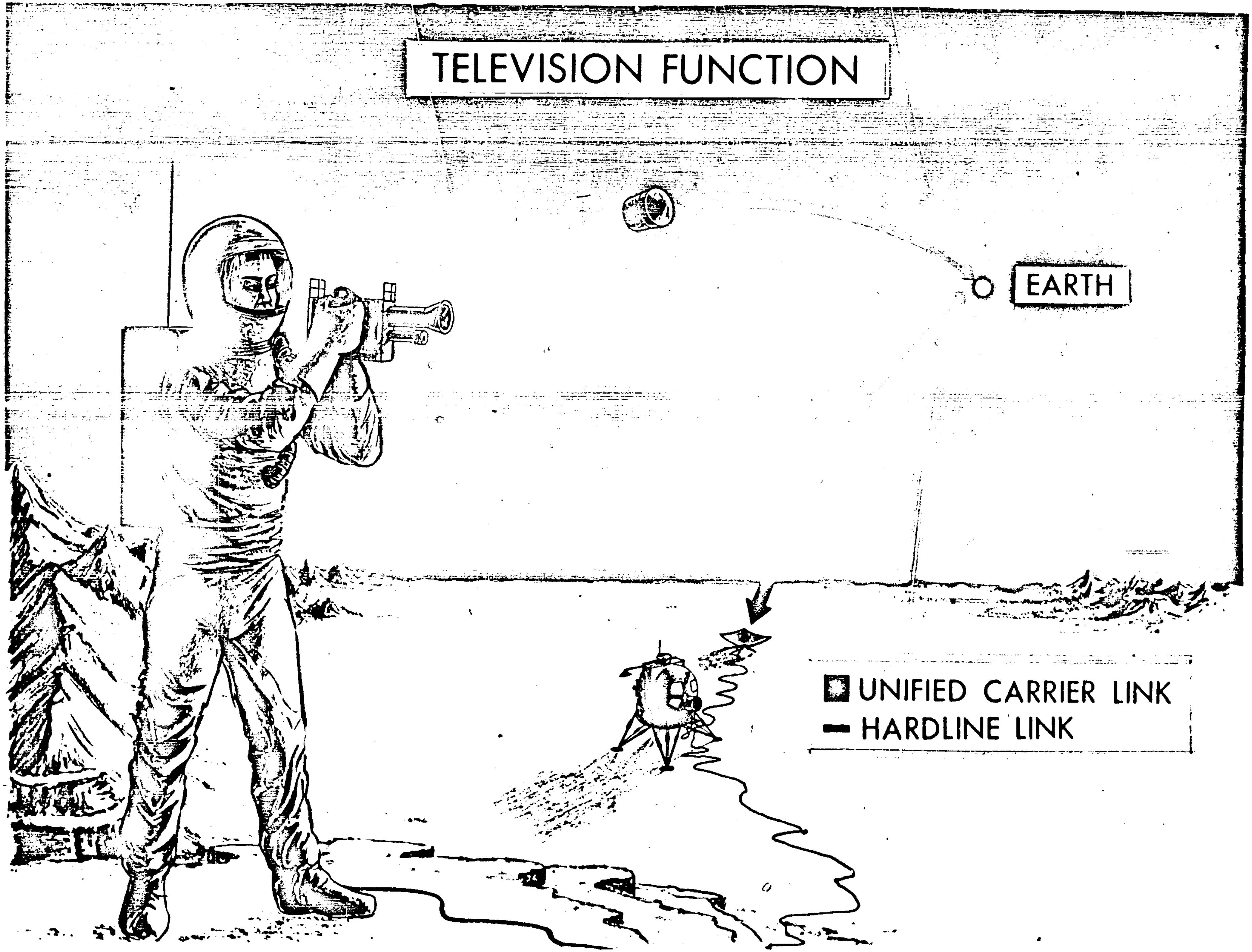


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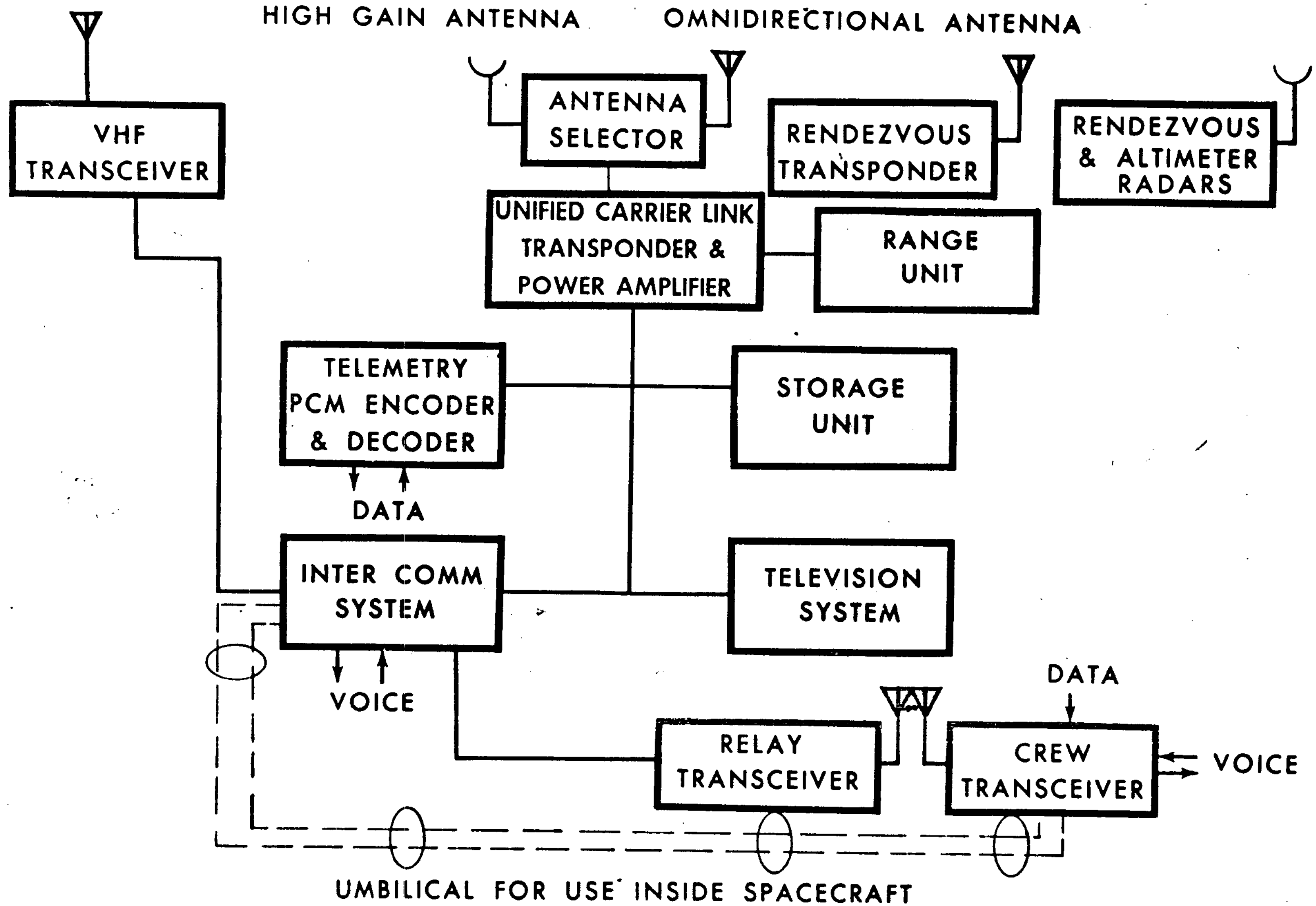
Figure 5

BLOCK DIAGRAM OF PLANETARY MISSION COMMUNICATION & TRACKING SYSTEMS USED ABOARD EXCURSION MODULE



BLOCK DIAGRAM OF PLANETARY MISSION COMMUNICATION & TRACKING SYSTEMS USED ABOARD COMMAND MODULE